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ALIGNMENT OF LIQUID CRYSTALS USING IRRADIATED LIQUID CRYSTAL FILMS

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FIELD OF THE INVENTION

The present invention is directed to alignment of liquid crystals using an alignment layer. More particularly, the invention is directed to alignment layers of irradiated liquid crystal films.

BACKGROUND OF THE INVENTION

Liquid crystals consist of anisotropic molecules. The average direction of the long molecular axis is called the director, ***d***. The director orientation is determined by the anchoring of the liquid crystal on rigid substrates and is characterized by the direction of the axis of easy director orientation, ***e***, and anchoring energy *W*.

Reorientation of the director caused by the application of an external electric field is the basis of operation of liquid crystal displays. The basic unit of liquid crystal devices is a liquid crystal cell, which includes two rigid substrates with a liquid crystal sandwiched between. To obtain uniform brightness and high contrast ratio it is desired to produce a uniform alignment of liquid crystals in the cell.

To produce uniform planar orientation of liquid crystals, several techniques involving different polymer materials are generally used.

One technique is the rubbing method. Polymer layers are deposited on the substrate and rubbed unidirectionally. The director, ***d***, is usually aligned parallel to the direction of rubbing in the plane of the substrate. A pretilt angle, φ, between the substrate and the director in the plane perpendicular to the substrate may be produced by this method.

The rubbing method produces stable planar alignment with strong anchoring. However, this technique has some drawbacks. In particular, dust and static electricity generated during the rubbing can cause defects in liquid crystal displays. Moreover, it is difficult to orient selected regions of the liquid crystal surface locally so that each region has a different orientation. It is difficult to obtain multi-domain alignment.

Another technique is the photo aligning method. Photosensitive polymer layers are deposited on the substrate and are irradiated by polarized UV light. Such layers possesses a light induced anisotropy axis that produces high quality planar alignment of the liquid crystal molecules in a preferred axial direction perpendicular or parallel to the polarization vector of the UV light beam, ***E***. Tilted alignment can be obtained by oblique irradiation of the polymer layer.

The photo aligning method produces stable planar and tilted alignment of most commercial nematic liquid crystals. In contrast to rubbing, no electrostatic charges or dust are produced on the aligning surface. Also, the direction of the easy axis and the anchoring energy can be locally varied by changing the direction of light polarization and the time of UV exposure.

An example of the photo aligning method can be found in U.S. Patent 5,389,698 to V.Chigrinov et al, which uses a photopolymer polyvinyl-cinnamate

aligning layer irradiated with plane-polarized light. Another example of the photo aligning method can be found in U.S. Patent No. 5,807,498 to Gibbons et al, which uses polyimides with di-aryl ketones and di-aryl ketones alignment layers.

Both of the above methods use special polymer materials to produce the alignment of the liquid crystals.

Another method uses light irradiation of a liquid crystal cell filled with dye-doped liquid crystals. This method can produce planar alignment of liquid crystals (Jap.Journ.Appl.Phys. v.34 (1995) 566). The mechanism of the alignment is postulated to be a result of absorption of the light by the dye molecules followed by their anisotropic adsorption onto the substrate. This method, however, requires the use of dye-doped liquid crystals to form an alignment layer.

United States Patent No. 5,032,009 to Gibbons et al. discloses exposing anisotropically absorbing molecules that are on a substrate, disposed in a liquid crystal medium, and the liquid crystals themselves to linearly polarized light. However, non-mesogenic molecules, such as a polyimide, are coated onto the substrate and exposed to linearly polarized light to produce alignment.

What is needed in the art is an alignment layer that can be formed from light irradiated liquid crystals.

It is therefore an object of the invention to provide a method of forming an alignment layer made from a liquid crystal film that is irradiated with light.

It is another object of the invention to provide a method of forming a liquid crystal cell that has at least one alignment layer made from a liquid crystal film that is irradiated with light.

SUMMARY OF THE INVENTION

The present invention provides a method for forming a liquid crystal alignment layer comprising: disposing liquid crystals in a solvent; depositing the liquid crystals and solvent on a substrate; removing the solvent to form a liquid crystal film; and irradiating the liquid crystal film with light wherein the wavelength of the light overlaps the absorption spectrum of the liquid crystal.

Also provided is a method of forming a liquid crystal cell comprising: providing two opposed substrates each covered with an electrode; disposing liquid crystals in a solvent; depositing the liquid crystals and solvent on at least one of the electrode covered substrates on the surface facing the other substrate; removing the solvent to form a liquid crystal film; irradiating the liquid crystal film with light wherein the wavelength of the light overlaps the absorption spectrum of the liquid crystal; placing spacers between the substrates; sealing three of the sides of the substrate to form a cell; filling the cell with a second liquid crystal; and sealing the cell.

Also provided is a liquid crystal display comprising a first and second cell wall structure, electrodes disposed on facing sides of said first and second cell wall structures, an alignment layer disposed on at least one of said electrodes, and first liquid crystals disposed within a space between the first and second cell wall structures, wherein the alignment layer comprises a liquid crystal film comprising second liquid crystals, wherein the liquid crystal film has been irradiated with light that overlaps the absorption spectrum of the second liquid crystals.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is graph of the irradiance of a xenon lamp.

Figure 2 is a graph of the absorption of the film of a liquid crystal mixture ZLI-4792 from Merck deposited on a substrate.

Figure 3 is a photomicrograph that shows the alignment in a liquid crystal cell that was prepared in Example 1.

Figure 4 is a schematic of a liquid crystal cell.

DETAILED DESCRIPTION OF THE INVENTION

A method is provided for forming a liquid crystal alignment layer. The method includes the steps of: disposing liquid crystals in a solvent; depositing the liquid crystals and solvent on a substrate; removing the solvent to form a liquid crystal film; and irradiating the liquid crystal film with light wherein the wavelength of the light overlaps the absorption spectrum of the liquid crystal.

The liquid crystal that can be used to form the liquid crystal layer can be any liquid crystal with molecules that have dichroic absorption matched to the irradiating wavelength and which undergo a photochemical transformation. Examples of photochemical transformation include, but are not limited to, cis-trans photoisomerization, photo-induced absorption or desorption, or photochemical reaction.

Generally, wavelengths of light in the UV region of the spectrum are used because liquid crystal molecules generally absorb light in the UV wavelengths.

Suitable examples of the liquid crystal include, but are not limited to, 4-cyano-4'-alkylbiphenyls, 4-cyano-4'-alkyloxybiphenyls, 4-alkyl-4'alkoxy-azoxybenzenes. Specific examples of compounds within these families are 4-cyano-4'-pentylbiphenyl, 4-cyano-4'-hexyloxibiphenyl and 4-butyl-4'metoxy-azoxybenzene.

Commercial mixtures containing all the above can be also used. Illustrative are the mixture E7 from BDH, Ltd, UK and the mixture ZLI 4792 from Merk, USA.

The liquid crystal alignment layer ranges from about a thickness that corresponds to the monolayer of LC molecules on substrate), which is about 2nm, to about 0.1 μm in thickness. Preferably, the liquid crystal alignment layer ranges from about 2nm to about 20nm in thickness.

The irradiating light of the present invention must contain a linearly polarized component, i.e. must be either linearly polarized or elliptically polarized, or partially polarized. Most preferably, the irradiating is providing by linearly polarized light. The irradiating light must have a wavelength in the absorption band of the aligning liquid crystal layer. Typically, the light will be in the ultraviolet range as the liquid crystal compounds have peak absorbtion in this range. Preferably, the light will have a wavelength within the range of about 200 to about 350 nm. The most preferred source of light is Hg- or Xe-lamps.

The direction of the easy axis is given by the polarization of the irradiating light (in most cases the easy axis is perpendicular to the polarization of the irradiating light). Therefore, the direction of the easy axis can be locally varied across the alignment layer by changing the direction of light polarization in the range 0 - 360°. The value of the anchoring energy is given by the irradiating intensity and exposure. Therefore, the anchoring energy can be locally varied across the alignment layer by changing the direction of light polarization and the time of the exposure. The typical range of the variety of the anchoring energy is about 10^{-4} - 10^{-2} erg/cm^2. Exposure times and light intensities vary widely with the materials and light source used and can range from about tens of seconds to about several hours.

Prior to irradiating, a mask may be placed over the liquid crystal film. The mask is removed after the film is irradiated. The mask can be any desired shape to provide a pattern to the liquid crystal film.

The liquid crystal film can be deposited on the substrate by any method. Suitable examples of depositing the film are spin coating and dip coating. For spin coating, the liquid crystal is dissolved in a solvent. The solvent can be any solvent that will dissolve the liquid crystal. Suitable examples of the solvent include, but are not limited to, aliphatic hydrocarbons (such as, hexane, octane, cyclohexane) aromatic hydrocarbons (such as, benzene, toluene, chlorobenzene), ethers (such as, ethylene glycol dimethylether, 1,4-dioxane, tetrahydrofuran), esters (such as, ethyl acetate, butyl acetate, diethyl carbonate,) ketones (such as, acetone, cyclohexanone, 2-butanone), and alcohols (such as, 2-propanol, ethanol, methanol). The solvent can be removed by any method, including evaporation at room temperature or with applied heat.

The substrate can be any material commonly used for fabricating liquid crystal cells. Materials such as glass, quartz or plastic can be used. The substrate materials can also be any materials commonly used for fabricating chips, for example silicon.

The liquid crystal alignment layer can then be incorporated into a liquid crystal cell. A liquid crystal cell typically comprises opposed substrates, electrodes on the substrates, alignment layers disposed over the electrodes, spacers between the substrates to control the thickness of the liquid crystal cell, and liquid crystals disposed between the substrates. Figure 4 is a schematic of a typical liquid crystal cell. Layers 11 and 15 represent the combined substrate and electrodes. Layers 12 and 14 represent the alignment layers. Layer 13 represents the liquid crystal material. And, layer 16 is a voltage source to power the cell.

The liquid crystal alignment layer can be placed on one or both of the substrates in the liquid crystal cell. When the liquid crystal alignment layer is placed on only one of the substrates, any known alignment material may be placed on the remaining substrate. Other alignment materials include, but are not limited to, rubbed or light-irradiated polyimides, rubbed polyvinyl-alcohol, light-irradiated polyvinyl-cinnamate, light-irradiated polysiloxane-cinnamates, oblique evaporated Al_2O_3.

The electrodes of the liquid crystal cell can be fabricated from any material known to be used for electrodes for liquid crystal cells. Suitable materials for the electrodes include, but are not limited to, indium-tin-oxide (ITO), stannic oxide SnO_2, aluminum, chromium, silver, or gold.

Additional information relating to the invention can be found in "Photoalignment of Liquid Crystals by Liquid Crystals" by Reznikov et al., Physical Review Letters, Volume 84, Number 9, 28 February 2000, pages 1930-1933, which is incorporated herein by reference.

SPECIFIC EMBODIMENTS OF THE INVENTION

Example 1

The liquid crystal mixture ZLI 4792, from Merck, was dissolved in hexane at a weight concentration of 0.5%. A droplet of this solution was deposited on a rectangular glass substrate and spin-coated for 20 seconds at 3000 rpm. Then the substrate was warmed to 50°C on a hot stage and maintained for 30 minutes. A uniform liquid crystal film with a thickness of less than 1 µm was produced on the substrate.

A portion of the liquid crystal film was irradiated with polarized UV light from a Xe-lamp. The irradiation spectrum of the lamp (Figure 1) overlaps the absorption spectrum of the liquid crystal film (Figure 2). The spectrum of the liquid

crystal deposited on the substrate is different from the spectrum of the bulk liquid crystal because of the interaction between the liquid crystal and the substrate. The film was exposed for 20 minutes at an intensity of 5 mW/cm^2. The polarization of the UV-light, E, was parallel to the long side of the glass substrate.

The glass substrate from above and another glass substrate with a rubbed layer of polyimide, NISSAN 7792 from Nisssan, were used to form a liquid crystal cell. The direction of rubbing on the substrate covered with the polyimide was parallel to the long side of the substrate. The substrates were separated by rigid 20μm spacers. The resulting cell was warmed to 100°C and filled with the liquid crystal ZLI 4792.

The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality twisted-planar alignment in the irradiated area (Figure 3). The director on the liquid crystal aligning layer aligned approximately perpendicular to the polarization of the irradiating UV light. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 2

The same procedure as described in Example 1 was used except that the cell was filled with the liquid crystal 4-cyano-4'-pentylbiphenyl (K15) from Merck. The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality weakly twisted planar alignment in the irradiated area. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 3

The same procedure was used as described in Example 1 except that the liquid crystal that was spin coated on the glass substrate and used for alignment was K15, and the cell was filled with the liquid crystal K15. The cell showed poor

alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality homeotropic alignment in the irradiated area. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 4

The same procedure as described in Example 3 was used but the K15 film was produced as described below.

The liquid crystal K15 was dissolved in isopropyl alcohol at a weight concentration of 0.2%. A chemically clean rectangular quartz substrate was put in this solution and maintained for 45 minutes. The substrate was taken out of the solution, washed in isopropyl alcohol for 20 seconds, and dried by a nitrogen gas stream to remove the solvent. As a result, a uniform liquid crystal film with a thickness comparable the thickness of the K15 monolayer was produced on the substrate.

The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a good quality twisted-planar alignment in the irradiated area. The director on the liquid crystal aligning layer was aligned 30° to the direction of rubbing on the surface covered with rubbed polyimide layer.

Example 5

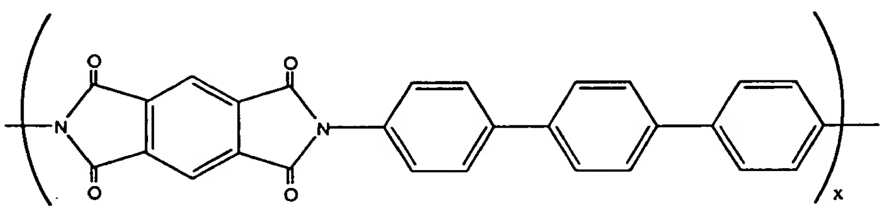
The same procedure as described in Example 1 was used except the glass substrates were covered with the liquid crystal K15 and the cell was filled with the liquid crystal ZLI-4792. The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality twisted planar alignment in the irradiated area. The director on the LC aligning layer aligned parallel to the rubbing direction of polyimide surface. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 6

The same procedure as described in Example 1 was used except the glass substrates were covered with the liquid crystal K15 and the cell was filled with the liquid crystal 4-butyl-4'metoxy-azoxybenzene (from Niopic, Russia). The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality twisted planar alignment in the irradiated area. The director on the liquid crystal aligning layer aligned parallel to the rubbing direction of polyimide surface. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 7

The same procedure as described in Example 1 was used except the liquid crystal K15 was deposited on a layer of a non-photosensitive polyimide, given by the following structure:



wherein x is a number from about 15,000 to about 70,000.

The cell was filled with the liquid crystal K15. The cell showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality twisted-planar alignment in the irradiated area. The director on the liquid crystal aligning layer aligned approximately perpendicular to the polarization of the irradiating UV light. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 8

The same procedure as described in Example 1 was used except that the liquid crystal K15 was deposited on a layer of a non-photosensitive polyimide, see Example 7, and the cell was filled with the liquid crystal ZLI 4792. The cell

showed poor alignment with a quasi-planar liquid crystal texture in the non-irradiated area and a high quality twisted-planar alignment in the irradiated area. The director on the liquid crystal aligning layer aligned approximately perpendicular to the polarization of the irradiating UV light. Thermal treatment (130°C for 1 hour) did not change the liquid crystal alignment in the irradiated area.

Example 9

The same procedure as described in Example 1 was used except that the liquid crystal K15 was deposited on a transparent conductive layer of indium tin oxide (ITO) and the cell was filled with the liquid crystal ZLI 4792. The cell showed a poor quasi-planar liquid crystal texture in the non-irradiated area and a high quality planar-twisted alignment in the irradiated area. The director on the liquid crystal aligning layer aligned approximately perpendicular to the polarization of the irradiating UV light. Thermal treatment (130°C, 1 hour) did not change the liquid crystal alignment in the irradiated area.

It should be appreciated that the present invention is not limited to the specific embodiments described above, but includes variations, modifications and equivalent embodiments defined by the following claims.